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COMBINED AIRFLOW MEASURING SYSTEM WITH NO DRIFT AND LOW NOISE LEVEL THROUGHT CONTINUOUS CALIBRATION OF AN INLINE ELEMENT USING A NON-VARIABLE TURBULENT PRESSURE DROP

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Combined airflow measuring system with no drift and low noise level through continuous calibration of an inline filter element using a non-variable turbulent pressure drop

1. Abstract

The system object of this article allows measuring the mass or volumetric airflow with very fast response time, low noise and no added drift due to clogging. It is composed of:

- An airflow sensing device (such as, but not limited to, an annubar pipe or a venturi pipe) in which at least one differential pressure sensor is used. In this device, the dynamic term of the pressure in a turbulent flow has been characterized to obtain the relationship between this pressure and the flow rate, so the measured pressure and the temperature define both the mass and volumetric flow rate. This device has the advantage of adding a very low pressure drop to the system and not changing with time due to clogging, but the measurements it provides are noisy due to the turbulent nature of the flow and because of this, fast changes in the flow (for example due to carriage movement or during diagnostics to quantify leaks, characterize fans, etc.) are hard to measure accurately.
- A passive element (such as, but not limited to, filters commonly used in Metaljet Fusion printers or Multijet Fusion printers to remove powder particles) that has an important pressure drop, which is measured by a differential pressure sensor. This element has often a linear dependence between flow and pressure drop (or parabolic if the flow is not completely laminar) and could provide an accurate noise-free instantaneous measure of the flow, but the constant or constants that relate the pressure and the flow change with the normal operation of the machine, as the filter gets dirty.
- An automatic closed loop process that calibrates the filter pressure drop constant with the average measurements of the turbulent flow sensor. The instantaneous flow measurements are then performed using the filter pressure drop instead.

This measurement mechanism applies to systems where:

- Accurate and fast measurements of airflows provide an advantage (such as 3D printing machines in which airflows over the powder bed control the solvent removal rate or the convective losses, or in cases where diagnostics are used periodically to characterize and control the operating point).
- It is not desirable to introduce an additional pressure drop in the air ducts.
- There are existing passive elements in which a high pressure drop (that depends on the flow but also varies with the use) can be measured.

Description of invention

2. Problems solved

Both in Plastics and Metals 3D printing, airflows inside the machine have an impact in thermal behavior, cooling of printheads and carriage, powder movement and solvent removal. Controlling the magnitude of this airflow is important for the repeatability of the process, but the benefits of measuring the flows with less noise also allow to reduce the time needed by some diagnostics that can be used for automatically quantifying leaks, calibrating the servos or characterizing open loop subsystems.

Not having flow sensors of any kind in the machine makes it impossible to calibrate the machine autonomously or to measure accurately the leaks/infiltrations terms. Having turbulent flow sensors improves this situation, but they do not work well when measuring quick variations (as they get masked by the turbulent nature of the flow).

With the solution object of this article, accurate and fast measurements can be performed, with no drift due to operation of the machine. Automatically recalibrating the gain of the pressure sensors used for controlling the dirtiness of the filters is a concept that uses elements which are often already in the machine for increasing the accuracy of the instantaneous measurements.

3. Prior solutions

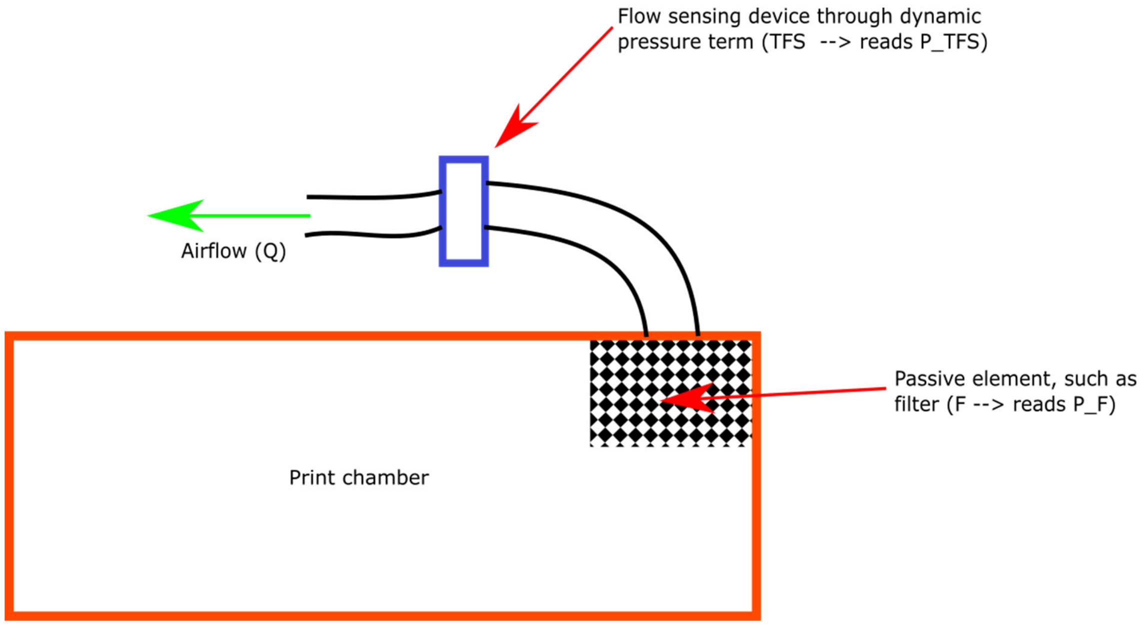
Previous solutions for quantifying the airflows inside the printers are:

- Using the RPM ratio and the fan laws to compare between different scenarios. This works well only when there are pure quadratic losses in all the elements, and requires characterizing some flows with external equipment outside of normal machine operation.
- Using directly the measurements coming from the airflow sensor devices (annubars). These devices do not add drift to the measurements with the use, but they give very noisy instantaneous measurements. They can be filtered, but then high frequency behavior such as the carriage movement or the working point changes in diagnostics are lost.

4. Description

The system is composed by the following hardware (schematic and reference CAD can be seen in Figures 1 and 2), through which a given Q airflow runs:

- A passive element (F), such as a powder filter, where a considerable pressure drop is produced. In the case of fine particle filters, the flow is laminar so the relationship between flow and pressure drop can be considered linear.
- One or multiple differential pressure sensors that allow measuring the pressure drop (P_F) in the passive element (F).
- An airflow sensing device (TFS) based on measuring the dynamic pressure term and the temperature in a turbulent flow. This device is previously calibrated in the same conditions in which it will operate, so the relationship between the flow that goes through it and the dynamic pressure term is fully characterized (parabolic).
- One or multiple differential pressure sensors that allow measuring the pressure difference (P_TFS) that corresponds to the dynamic term of the turbulent flow.
- One or multiple temperature sensors that allow measuring the temperature (T) in one or more points (usually at the TFS).



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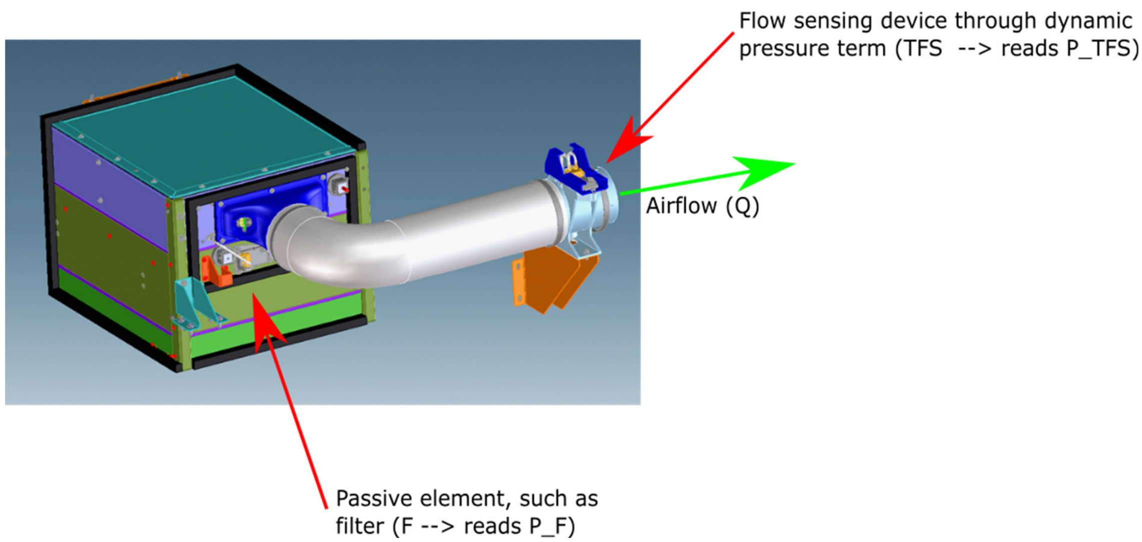
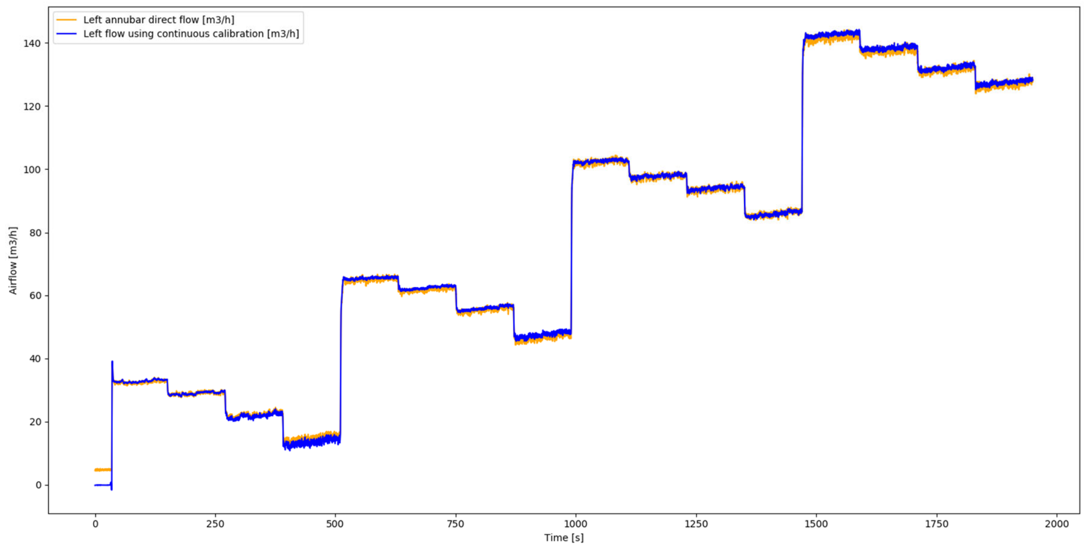
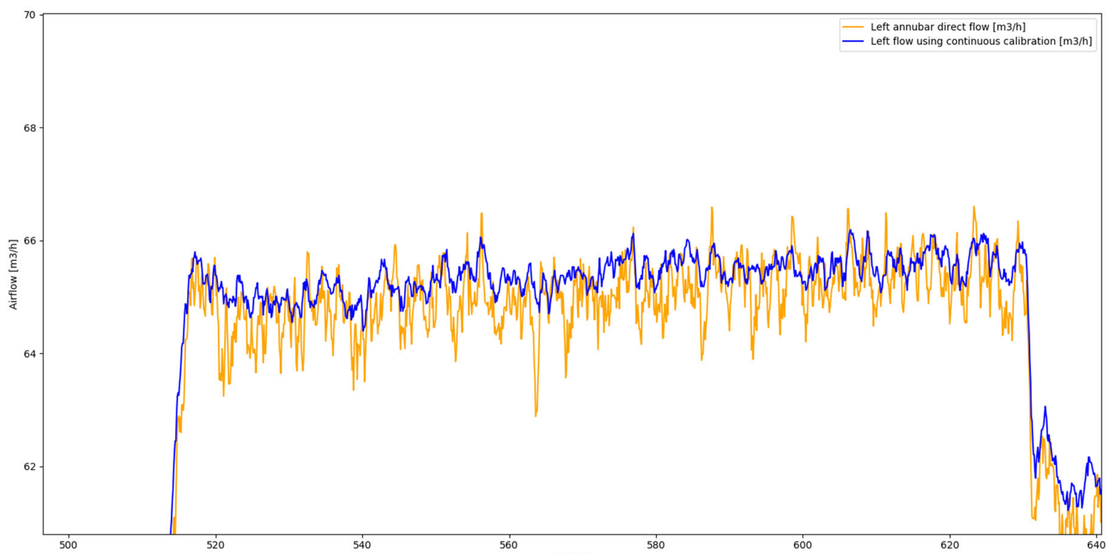


The measurement procedure is the following:

- The pressure TFS, the temperature and the characterization curve of the annubar device are used to obtain the annubar direct flow measurement (Q_direct_annubar).
- The pressure drop P_F in the filter is continuously read, and for slow behaviours it is known to be K*Q_direct_annubar in the case of fine particle filters. K can be adapted with a mechanism similar to a PI servo, where the error is P_F-Density(T)*K*Q_direct_annubar and the integral term filters the turbulent behaviour but does not affect the real K changes due to clogging, which will be a lot slower.
- The final airflow measured by the system is calculated directly from the filter pressure drop as P_F/(K*Density(T))

In Figures 3 and 4 it can be seen that comparing the direct measurements of the annubar flow sensors with the instantaneous measurements the calibrated filters give, the peak to peak distance of the noise in the second case gets reduced from a 7.5% to a 2% in this example, which would allow faster calibrations, better airflow control, etc.





5. Advantages

This solution makes use of elements that are often already used in 3D Printing machines (powder filters) to increase the accuracy of the flow sensor devices. The recalibration process is automatic, continuous and not computationally costly (a mechanism similar to a servo can be used to regulate the gain).

The measurements that are achieved with this system do not mask phenomena with a small time constant: no additional low pass filtering is necessary for removing the noise, so carriage movement effects can be seen if necessary, and during diagnostics where different operating points are tested, the changes can be done considerably faster as less measurement points will be necessary to obtain a reliable measure. This enables to improve the characterization, the adaptive control and the diagnosability in the air management system.

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